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ABSTRACT

The purpose of this study was to examine the effectiveness of an analogy activity designed to overcome junior high school students' misconceptions about the microscopic views of phase change. Eighth grade students (N=80) were randomly assigned to either a control group receiving traditional teaching, or an experimental group participating in the analogy activity which asks the students to act as particles and work together to perform the conditions of phase changes. Findings indicate that the students of the experimental group did not perform statistically better than those of the control group in an immediate posttest. On the delayed test, a comparison between the two groups indicates that the analogy activity had a positive impact on students' understanding of certain concepts. Contains 26 references. (DDR)

Overcoming Eighth Graders' Misconceptions about Microscopic Views of Phase Change: A Study of an Analogy Activity

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Overcoming Eighth Graders' Misconceptions about Microscopic Views of Phase Change: A Study of an Analogy Activity

Abstract: This study was conducted to examine the effectiveness of an analogy activity, which was designed to overcome junior high students' misconceptions about the microscopic views of phase change. Eighty 8th graders were randomly assigned to either a control group, receiving traditional teaching, or an experimental group, conducting the analogy activity, which asked students to serve themselves as particles and then work together to perform the conditions of phase changes. Through analyzing these students' drawings representing the atom arrangements for the three states of some substances, it was found that the students of experimental group did not perform statistically better than did those of control group in an immediate posttest. However, the comparisons of a delay test between these two groups indicated that the analogy activity had clearly positive impacts on students' understanding on these scientific concepts in light of long-term observations.

In the paradigm of constructivism, educators agree that students' prior knowledge plays an essential role on subsequent learning (Ausubel, Novak & Hanesian, 1978; Driver & Easley, 1978; Driver & Oldham, 1986; Tsai, 1996). During the past three decades, the most important contribution of science educators is to explore what science-specific schemata learners possess. Consequently, science educators have surveyed students' scientific misconceptions, or namely alternative conceptions, in many domain-specific topics (e.g., the most recent studies, Greca & Moreira, 1997; Langley, Ronen & Eylon, 1997; Posada, 1997; Sanger & Greenbowe, 1997). Perhaps, the studies of students' misconceptions related to the particulate nature of matter yield the most fruitful findings. It is found that these misconceptions are widely held by learners in various grade levels and they are fairly resistant to change by conventional teaching strategies (Wandersee, Mintzes & Novak, 1994). However, knowing learners' misconceptions is not equal to having an instructional methodology that could change them. The study reported here is an attempt to overcome junior high school students' misconceptions about the Microscopic Views of Phase Change (MVPC) by using a role-playing analogy activity.

Literature Review and Rationale

Understanding the particle nature of matter plays an important role on learning chemistry. Gabel's (1991) study showed that students' chemistry achievement could be improved through emphasis on the particle nature of matter. A substantial body of research literature has reported students' misconceptions concerning the particle nature of matter, and some studies more related to MVPC are reviewed in this paper. First, students likely lack the ability to explain the state change of a substance through a microscopic perspective. For example, a study completed by Shepherd and Renner (1982) indicated that none of the high school students in their research held scientifically correct views in explaining the differences of solids, liquids, and gases by using a sound particle model. Stavy (1988) explored how students defined "gas" and found that none of the 7th graders used particle model as its definition and only 25% of the 8th graders did so.

Even though students could use particulate model to describe the phase change, they have some misconceptions. For instance, Pereira and Pestana (1991), who asked grade 8-12 students to draw the representation of water in its three phases, found that many high school students thought that the particle size would increase as a result of phase change. Furthermore, very few of them mentioned the movement of the particles (strikingly, those who did so were *lower* graders), and most of them had some misunderstandings about the relative distance between the particles for the three states. It should be noted that the subjects in Pereira and Pestana's study came from the participants in a chemical Olympiad event, who performed academically much better than did average students in chemistry. Hence, common students may have poorer understandings on these scientific concepts.

Griffiths and Preston (1989) revealed a similar finding that high school students believed that the particle size of a substance would increase when it changed from liquid state to gaseous state or when it was heated. By contrast, although many secondary school students in Dow, Auld, and Wilson's (1978) research perceived that the particle size would vary at different phases, they tended to believe that particles in the liquid or gaseous state would be *smaller* than those in the solid state. The students also showed a tendency to use their perceptions on macroscopic changes of a substance to infer its phase changes occurring at the microscopic level. For example, they thought that the particles per se would melt and get hot from solid state to liquid state.

Students not only believed that the particle size would change quantitatively during phase change, but also asserted that the particles, somewhat, would change "qualitatively." Osborne and Cosgrove (1983) investigated New Zealand secondary school students' conceptions about the state change of water, and these researchers found that, even among 17-year-olds, 30% of them believed that water changed to oxygen and hydrogen, as it evaporated. Similarly, nearly 40% of them held the idea that the bubbles in boiling water were made of oxygen and hydrogen, and 35% theorized that the water was condensed from the oxygen and hydrogen outside a cold jar. All of these could be viewed as "reinforced" misconceptions resulting from science instruction (see Gilbert, Osborne & Fensham, 1982), as students have acquired the scientific view that a water molecule consisted of hydrogen and nitrogen atoms. The study by Bonder (1991), who explored entering chemistry graduate students' ideas, revealed a similar finding that 25% of them assumed that the bubbles in boiling water were made of air or oxygen or hydrogen gas. In sum, students often share the view that the atoms would be totally separated or recombined as a result of phase change.

As mentioned previously, students seldom express the kinetic nature of particles (Pereira & Pestana, 1991). Even though they have such an idea, they still have some misconceptions. For example, by surveying nearly 1000 Scottish junior school students, Dow, Auld, and Wilson (1978) found that many of them believed that particles in liquid and gaseous state were in constant motion, but there was no movement in solid state. According to the literature review above, this study concluded the following four major misconceptions of MVPC held by students:

(1) They believe that the particle size will vary in different phases.
(2) They have misconceptions about the relative distance change between particles for the phase change.
(3) They believe that particles will be separated or recombined as a result of phase change.
(4) They hold some misconceptions about the kinetic views of particles, or they did

not have any idea concerning the intrinsic motion of particles.
These four misconception categories, in this paper, are referred as "size," "distance," "reorganization" and "motionless."

Recently, many educators have advocated the use of analogy to promote students' conceptual change (Dagher, 1994; Stavy, 1991). Some research-based analogies which aimed at overcoming students' alternative conceptions about the MVPC have been presented in educational journals (e.g., Flick, 1991; Stavy, 1991). However, Flick's analogy may be somewhat misleading. She used the grinding of a sugar cube as an analog representing MVPC of water. Such an analogy could guide students to understand that ice or steam is still water after phase changes just as sugar is still sugar after grinding. This analogy, nonetheless, may reinforce students' popular misconception that the particles constituted in ice, water, and steam are different in size (i.e., the "size" misconception summarized above). The present study proposed a role-playing activity as an analogy to address students' four aforementioned major misconceptions about MVPC, and then examine its effectiveness in prompting students' conceptual change of MVPC.

Subjects

This study was conducted with 83 eighth graders in a suburban public school in Taipei City, Taiwan. These students were randomly assigned to two groups: one for control group, which received traditional-approach instruction about MVPC (e.g., lectures, readings), and the other for experimental group, which conducted the research treatment of an analogy activity. There were 42 students in control group and 41 in experimental group. However, due to some students' unexpected absence, 41 control subjects and 39 experimental subjects completed all of the tests (including pretest, posttest and delay test, described later) in this study. Hence, only these 80 students' data were included for final analyses. It should be noted that when this treatment was conducted, all of these students had been taught about the ideas of the atomic theory, particle nature of matter and MVPC by traditional instructional strategies (e.g., lecturing) six months ago. The subjects in this study were "re-taught" about the concepts of MVPC.

Research Treatment: An Analogy Activity

The analogy activity was proceeded as follows. To demonstrate the phase changes of Br_2, the students were asked to work as a team of two persons. The teacher informed that all students were identical Br atoms, and the two persons in each team should be hand in hand in "any" situation. When the teacher assumed the temperature of -10°C (in Br_2's solid state), the students, as teams of two persons, were asked to cram together with minute motion (slow dancing). When the teacher assumed the temperature of 20°C (in Br_2's liquid state), the students, still as teams, were asked to have a more impetus movement. It could be imagined that in order to have more violent motion, students' original organization would become looser, unconsciously. The same activity rule was applied to the temperature of 75°C (Br_2's gaseous state). In sum, students in the experimental group role-played Br atoms at different temperatures and phases. These students were also informed that similar analogy activities could be used to explain the phases of other substances (e.g., NH_3, the students move as a team of four together).

It is expected that this analogy activity could address students' four major misconceptions of MVPC, that is, "size," "distance," "reorganization" and "motionless." For example, students could infer that the distance between particles, but not the size of particles, would change as a result of phase change, because the distance between teams changed in the activity but the "size" of every student did not change. As another example, since students were asked to move as original teams in any phase, this activity could inform students that the particles would move on the same bases in any phase. Hence, it is impossible that when water becomes steam, the steam will change from water molecules to isolated hydrogen or oxygen atoms or molecules. That is, the particles would not be separated or recombined as a result of phase change (with few exceptions, e.g., Sulfur). Also, students would acquire the idea that the particles would vibrate more wildly as a result of increasing temperature, but in any state the particles would continue moving. The treatment, including the teacher's explanation of this analogy activity, students' role-playing, and teacher-students' interactive discussion about the similarities and differences between the implications of this activity and scientific concepts of MVPC, lasted approximately 50 minutes. The control group, at the same period of time, was taught by another science teacher through traditional instruction of MVPC (e.g., lecturing, reading of textbooks).

Data Collection

Research data were gathered through analyzing students' drawings about the particle arrangements of matter of three different phases. A total of three tests were administered for this study: the first one was done one week before the research treatment (pretest), the second one was completed an hour after the treatment (posttest), and the final one was conducted four weeks after the treatment (delay test). In each test, students in both groups were asked to draw particle pictures to represent the particle arrangement of one substance of three phases (e.g., NH_3). This way of data gathering is similar to that used by Pereira and Pestana (1982). The drawing substance was identical for both groups in each test. They were also instructed that they had to draw at least two sets of molecules or atoms of the substance for each phase. All students were well informed that they could use word explanations in the drawings, if they desired. The students, who completed all of these tests, would be viewed as the effective samples in this study. There were 41 students in control group and 39 in experimental group, finally.

Students' drawings were analyzed by two independent school science teachers on the basis of the four major aforementioned misconceptions: "size," "distance," "reorganization" and "motionless." For each misconception category, the teachers decided an option among "correct," "incorrect" and "unidentifiable" on every drawing. The analysts did not acquire any information about the appertaining group (either control or experimental) on each student's drawing. The average agreement between these two examiners was .92, and the items with analysts' disagreement would finally be counted as "unidentifiable." Only the results with analysts' agreed "correct" and "incorrect" responses were further used for statistical (chi-square) analyses.

Results

According to the research data gathered from pretest (Table 1), students in both groups had similar understanding about the MVPC (n.s., for each misconception category). Although these students had received relevant instruction six months ago, more than half of them[1] had misconceptions concerning the size of the particles ("size" category) or believed that the atoms would be separated or recombined as a result of phase change ("reorganization" category). However, many of the students held scientific views about the distance differences between particles for the three states. Only five of the students in control group as well as two in experimental group mentioned or showed kinetic views of the particle model in their drawings; however, not all of them held scientifically correct views. It might be difficult for the students to represent such ideas in their drawings or they might simply forget the intrinsic motion of the particles.

(Insert Table 1)

The posttest was conducted an hour after the treatment. According to the data presented in Table 2, clearly, in most of the categories, students in both groups achieved much better understandings than what they performed in pretest; i.e., the correct student percentage and number for each misconception category increased. The instruction presented either in a traditional way or in the analogy activity improved students' understandings of MVPC. More importantly, this study had larger effective sample size in posttest for almost every category. For example, a total of 7 students in control group mentioned the kinetic views of particle model in their drawings (only 5 in pretest), and the number of students in experimental group who showed the same views increased from 2 in pretest to 18 in the posttest. This also implies that the strong impression from the analogy activity, which asked students to "dance" anytime, to a certain extent, may have contributed to such a dramatic number increase in the experimental group.

(Insert Table 2)

For the categories of "size", "reorganization," and "motionless," students' performances between these two groups were not statistically different by chi-squire analyses. Such an immediate test did not show significant differences between both groups for these concepts. However, the correct percentage of experimental subjects was significantly higher than that of control subjects in the "distance" category. Such significant differences came from the fact that the students in experimental group greatly improved their understanding as a result of the treatment (correct percentage increases from 64% in pretest to 82% in posttest), but the students in control group had performance "regression" in the posttest (from 77% in pretest to 59% in posttest). A possibility for the "worse" performance of the control group students might stem from the factor, "statistical regression," related to internal validity of research design (see Campbell & Stanley, 1963, p.175), because the control group achieved very high correct percentage in pretest for this category. However, the subjects in this study were truly randomly assigned to the two groups; therefore, both groups had similar possibility to experience such a regression.

By and large, when compared with traditional teaching strategies, this analogy treatment did not show clearly strong positive impacts on students' understandings about MVPC. It is also doubted that such an immediate test might simply assess students' pure recall, not real understanding; or even worse, it would favor the students who received traditional instruction, somewhat encouraging learners to memorize some scientific information.

(Insert Table 3)

The results in Table 3 illustrate some encouraging findings for the delay test, administered four weeks after the research treatment. The students in experimental group acquired better understandings in "size," "distance" and "reorganization" categories than those in control group did. Moreover, although the correct percentages in "motionless" category were not statistically different between both groups, there were 15 subjects in experimental group showing the kinetic views of the particles in the drawings (while 13 of them were scientifically accurate) but only three subjects in control group spontaneously mentioned the same ideas (while two of them were correct). That is, even after a month, many experimental subjects still had strong impression concerning the intrinsic motion of particles from the analogy activity, but almost all of control subjects might forget this idea.

The statistically significant differences between both groups in "size," "distance," and "reorganization" categories resulted from the fact that the correct percentage (or number) of control subjects largely decreased from posttest to delay test, whereas the percentage (or number) of experimental subjects merely slightly regressed from posttest to delay test. For instance, 59% of the students (or 19 students) in control group held scientifically correct ideas in posttest for "size" category but only 35% (or a total of 11 students) of them possessed the same ideas in the delay test. On the other hand, 65% of the learners (or twenty subjects) in experimental group had accurate views of "size" in posttest and still as many as 62% of them (or 18 students) expressed the same views. Similar comparisons and findings could be applied to the other two misconception categories.

(Insert Figure 1)

Figure 1 further displays all correct number of students across three tests for both groups. It shows that relatively few students had scientifically accurate concepts about kinetic views of MVPC in their drawings and those showing such views were likely those in posttest and delay test of the experimental subjects. This indicated that when compared with traditional instructional methods, the analogy activity was useful in overcoming students' "motionless" misconception of MVPC. Moreover, Figure 1 illustrates that students in experimental group, in some categories, likely performed better in posttest (than control subjects did), but experimental subjects clearly showed much better understandings in all categories of MVPC in delay test than students in control group did. In conclusion, this study revealed that the analogy activity might not show obviously favorable results on the immediate test, but it is useful to help students construct the concepts of MVPC and these constructed concepts could last much longer than did those received from traditional instruction.

Further analyses about the content of students' misconceptions of MVPC across three tests of both groups discovered the following. In the "size" misconception category, most students holding scientifically incorrect ideas (about 73% of incorrect students across three tests of both groups) believed that the particle size in the gaseous state would be larger than that in the solid state. In the "distance" category, many incorrect students (53% among all incorrect students) had the concept that there was no change of the distance across three states. In the "reorganization" category, the idea that particles would be separated from solid state to liquid (or gaseous) state was most widely shared among incorrect students (43%). In the "motionless" category, eight among 12 incorrect students (across three tests of both groups) theorized that there was intrinsic motion of particles in the liquid and gaseous state but not in the solid state. The content of these major misconceptions was similar to that revealed by studies reviewed previously (e.g., Pereira & Pestana, 1991; Griffiths & Pretson, 1989). Such a clear tendency of students' MVPC misconceptions showed that students holding scientifically inaccurate views had similar reasoning or mental models to interpret MVPC. Moreover, the major misconceptions above were almost found among "incorrect" students across three tests on both groups, indicating that these types of misconceptions for some students, either in control group or experimental group, were very resistant to change. However, the research results presented earlier supported that the analogy activity was still helpful to promote "more" students' conceptual change about MVPC.

Discussion

The pretest results showed that students in either control group or experimental group did not have appropriate understandings about the MVPC, though they had been instructed the same scientific concepts by traditional methodology six months ago. In light of long-term observations, traditional teaching strategies likely failed to challenge these students' alternative conceptions of MVPC. Students in both groups mostly improved their understanding of MVPC after being "re-taught" these concepts. Both the traditional instruction and role-playing analogy activity had positive impacts on the immediate posttest, except the control subjects' performance concerning the concepts of the distances between particles. The students who participated in the analogy activity, in many cases, did not perform statistically better than those in traditional group did.

The data from the delay test revealed that the performance of the learners receiving traditional instruction was dramatically regressed four weeks after the instruction, but on the other hand, there was merely a little regression for experimental subjects. The treatment showed its positive impacts on students' long-term understandings. This implies that traditional teaching strategies, which may implicitly encourage students to use rote memorization in learning science (Roth, 1989; Feynman, 1986), could not enhance students' long-term understandings. The analogy activity proposed in this study, however, shows instructional potential to help students construct scientific concepts of MVPC and then to strengthen the retention of scientific knowledge. In addition, much more students in experimental group spontaneously illustrated the kinetic views of particle model in their delay-test drawings, indicating that the analogy activity is effective to address the intrinsic motion of particles.

There were some limitations of this study. Because there were some unexpected school contextual constraints during the process of conducting this study, the researcher cannot properly conduct students' in-depth interviews. Consequently, learners' drawings were used as the sole source of research data. This might lose some important insights for further exploration. For example, some students might have scientifically accurate concepts, but they simply cannot express their ideas in the drawings. This could somewhat explain the fact that few students showed kinetic views of particles in the tests. Also, if the interviews had been conducted, the researcher could examine the consistency between students' verbal expressions and their drawings, and then assess the validity of research data gathering. Further, some students' ideas are also needed to elucidate in details, such as how the students constructed understanding of the analogy activity and how their understanding of the analogy related to the scientific concepts. A six-month or one-year delay test to examine these learners' understanding of MVPC is recommended for further discussion about the effectiveness of this analogy activity.

Conclusion

Science educators always seek some teaching strategies to promote students' meaningful learning in science classrooms. As opposed to rote learning, knowledge acquired meaningfully is firmly stored students' cognitive structures for further retrieval. From this perspective, the analogy activity proposed in this study showed positive evidence for junior high students' meaningful learning.

This analogy activity also differs from the use of some other analogies in science classrooms proposed by some earlier researchers. Past analogy-oriented learning activities focused on applying learners' "anchoring intuitions" to explain new scientific conceptions; however, the analogies were still presented in a lecture or traditional-aligned format (e.g., Flick, 1991; Stavy, 1991). The analogy used in this study was a role-playing and student-centered activity; hence, students were encouraged to "learn from playing." The instructional strategy of using this analogy activity is also compatible with the features of so-called "constructivist learning environments," emphasizing the autonomy and student-centered mode of learning (Taylor & Fraser, 1991; Tsai, 1997). The initial success of this analogy activity found in this study could support the practice of constructivism in science education. Furthermore, educators could employ similar analogy activities to illustrate the microscopic views of chemical reactions. Through playing these activities, students may well perceive how atoms interact when chemical reactions occur, and understand the ideas about the conservation of mass during chemical change. This study provides another promising direction to use analogy in science classrooms. Potential applications of this analogy activity could be further explored in the future.

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Table 1. The results of pretest between control group and experimental group

		Control Group(#,%)	Experimental (#,%)	Chi-squire(D.F.=1)
Size	Correct	9(29%)	10(33%)	.129, n.s.
	Incorrect	22(71%)	20(67%)	
Distance	Correct	23(77%)	18(64%)	1.05, n.s.
	Incorrect	7(23%)	10(36%)	
Reorganization	Correct	9(53%)	8(44%)	.245, n.s.
	Incorrect	8(47%)	10(56%)	
Motionless^	Correct	3(60%)	1(50%)	.05, n.s.
	Incorrect	2(40%)	1(50%)	

n.s.: not statistically significant at the .05 level

^: The cells have expected counts less than 5 for chi-squire analysis.

Table 2. The results of posttest between control group and experimental group

		Control Group(#,%)	Experimental (#,%)	Chi-squire(D.F.=1)
Size	Correct	19(59%)	20(65%)	.174, n.s.
	Incorrect	13(41%)	11(35%)	
Distance	Correct	19(59%)	27(82%)	3.89*
	Incorrect	13(41%)	6(18%)	
Reorganization	Correct	16(53%)	26(74%)	3.05, n.s.
	Incorrect	14(47%)	9(26%)	
Motionless	Correct	5(71%)	14(78%)	.107, n.s.
	Incorrect	2(29%)	4(22%)	

* $p<.05$; n.s.: not statistically significant at the .05 level

Table 3. The results of delay test between control group and experimental group

		Control Group(#,%)	Experimental (#,%)	Chi-squire(D.F.=1)
Size	Correct	11(35%)	18(62%)	4.17*
	Incorrect	20(65%)	11(38%)	
Distance	Correct	13(43%)	21(72%)	5.02*
	Incorrect	17(57%)	8(28%)	
Reorganization	Correct	10(32%)	19(61%)	5.16*
	Incorrect	21(68%)	12(39%)	
*Motionless^*	Correct	2(67%)	13(87%)	.68, n.s.
	Incorrect	1(33%)	2(13%)	

* $p<.05$; n.s.: not statistically significant at the .05 level

^: The cells have expected counts less than 5 for chi-squire analysis.

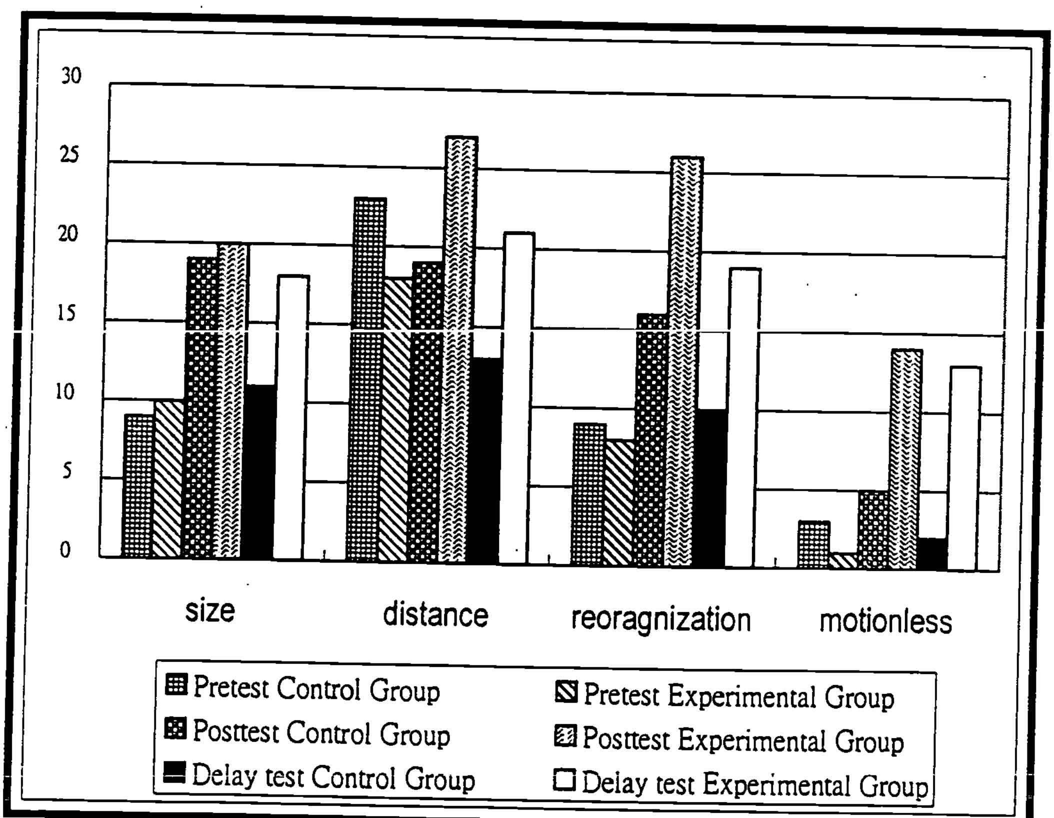

Fig. 1: Number of correct students between control and experimental groups across three tests

Note

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[1] This result interpretation is based on effective sample. In this part of result presentation, the percentage data were calculated on the basis of effective sample. As mentioned previously, the effective sample represented students having agreed "correct" or "incorrect" score between two analysts. This way of analysis may result in different sample size between control group and experiment groups in each misconception category, and then make some "unfair" comparisons between these two groups; therefore, this study employed chi-square analyses (comparing percentage of two groups). More importantly, if the research results are carefully examined, it could be found that, except the "motionless" category, the final effective sample in each misconception category for each test are almost the same. For example, in pretest, the effective sample of "size" misconception category for control group was 31 while for experimental group was 30. Similar results may be found in other categories. Hence, this way of analyses may have resolved the problem of "unfair comparisons," as this study mainly compared the percentage differences between control and experimental groups, and these two groups almost had equal effective sample in each misconception category of each test. As regards to those students viewed as ineffective sample subjects, most of them did not show any (either scientifically accurate or inaccurate) understanding about MVPC in their drawings. There were approximately 18% of students in both groups belonging to this type.

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